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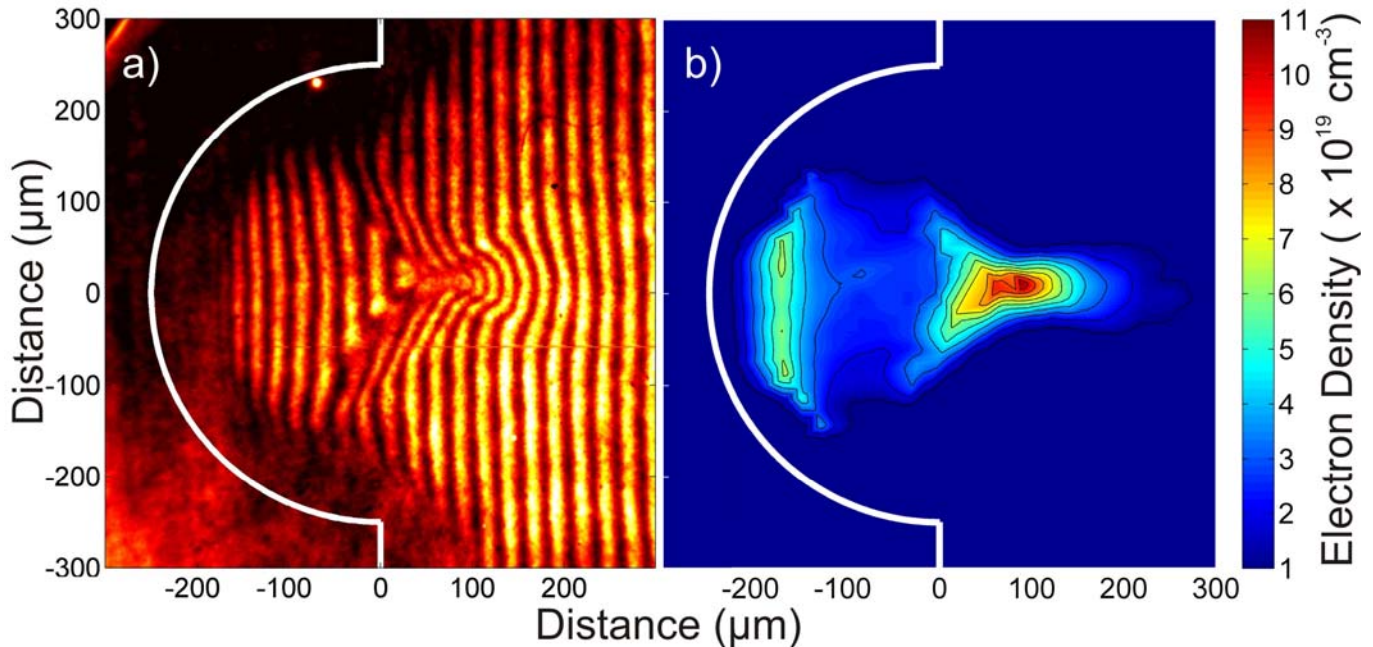


Fig. 1. a) Soft x-ray interferogram of a plasma created by laser irradiation of a 500 μm diameter semi-cylindrical Al cavity at an intensity of $1.1 \times 10^{12} \text{ W cm}^{-2}$ with a 120 ps duration laser pulse, and b) the resulting electron density map. The interferogram depicts the plasma 4.4 ns after the peak of the laser irradiation pulse.

Abstract – A table-top capillary discharge soft x-ray laser was used to acquire high contrast interferograms that map the evolution of dense aluminum plasmas created by laser irradiation of a 500 μm diameter semi-cylindrical cavity with 120 ps optical laser pulses of $\sim 1.1 \times 10^{12} \text{ W cm}^{-2}$ peak intensity. The measured electron density maps, that were compared with simulations, show that the plasma converges on axis, where it collides to form a localized region with density exceeding $1 \times 10^{20} \text{ cm}^{-3}$.

Index terms – soft x-ray laser, plasma diagnostics, soft x-ray laser interferometry, colliding plasmas.

Plasmas created by intense laser pulses irradiating solid targets usually expand in directions perpendicular to the target surface, along the strong pressure gradients that are generated by the high temperatures and densities near the wall. For concave target geometries, this direction of expansion can force the laser created plasma to converge into a focal region where it can collide with itself. For example, laser heating of a semi-cylindrical cavity (half-hohlraum) accelerates plasma towards the axis of the cavity where plasma interactions can range from stagnation to extended interpenetration depending on the degree of collisionality of

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the plasma [1]. Detailed electron density maps are very useful to understand the dynamics of these colliding plasmas and for benchmarking plasma simulation codes. However, they are difficult to obtain using optical laser probes due to the presence of strong density gradients that deflect the probe beam. Soft x-ray laser interferometry is a powerful plasma diagnostic tool that has the ability to access very high densities and large scale length plasmas with a reduced refraction and free-free absorption of the probe beam, allowing for the generation of detailed maps of the electron density in high density plasmas [2], [3].

Interferograms were obtained using a Ne-like Ar 46.9 nm table-top capillary discharge soft x-ray laser probe beam [4] and an amplitude division soft x-ray interferometer [3]. The probe beam was configured to deliver pulses of ~ 1 ns duration and ~ 0.15 mJ of energy. The good spatial coherence of this laser assists the generation of interferograms with high fringe visibility. The skewed Mach-Zehnder interferometer uses gold coated diffraction gratings as beam splitters and grazing incidence gold coated mirrors to achieve a high throughput of $\sim 6\%$ per arm. The dense colliding plasma was created by focusing 600 mJ pulses of 120 ps duration from a $\lambda = 800$ nm Ti:Sapphire laser onto the surface of a semi cylindrical target. The laser beam was smoothed by a vacuum spatial filter and it was shaped into a 310 μm wide, 1.5 mm FWHM long line focus by a pair of cylindrical lenses. The targets consisted of 500 μm diameter semi-cylindrical cavities machined onto the edge of a 1 mm thick aluminum slab. The targets were placed along the zero order arm of the interferometer. The plasmas were imaged with 25X magnification onto a microchannel-plate/CCD detector using Sc/Si multilayer mirrors.

A sequence of interferograms was acquired to map the evolution of the plasma. The interferograms show the early creation of a plasma that expands away from the wall to converge in a small region near the axis of the cavity, where it collides forming a dense plasma focus. The resulting build-up of density at the focus develops as early as 1.5 ns after the peak of the irradiation pulse, with the electron density progressively increasing to exceed $1 \times 10^{20} \text{ cm}^{-3}$. Figure 1a shows a high contrast soft x-ray interferogram acquired 4.4 ns after the irradiation pulse. The large number of fringe shifts observed slightly to the right of the axis of the cavity describes the high density focal region. Figure 1b shows the electron density map constructed from the interferogram.

The single fluid radiation hydrodynamics code HYDRA was used to simulate the 2D symmetric experiment described above and generate time-dependant 2D maps of the electron density and other plasma parameters [5]. The code uses an Arbitrary Lagrangian-Eulerian grid. The simulations show that the peak electron density ($1.1 \times 10^{20} \text{ cm}^{-3}$) and electron temperature (~ 50 eV) at the focus occurs ~ 2.6 ns after the irradiation pulse, in good agreement with the experiments. The laser model included the Gaussian-shaped irradiation pulse which shows the creation of a hotter plasma

at the bottom of the groove. This plasma expands more rapidly and reaches the axis of the cavity first, where it converges forming the observed high density plasma focus. The later arrival of additional plasma created by plasma radiation-induced ablation of the entire target cavity wall causes the electron density at the focus to remain high until ~ 7 ns after the arrival of the irradiation pulse. Subsequently the density is observed to relax as the plasma expands and cools. The ion-ion mean free-path is computed to be nearly two orders of magnitude smaller than the plasma focus size, an indication that the plasma is highly collisional. The good agreement between the experimental results and the simulations with the fluid code HYDRA, which can not model interpenetration, indicates that the plasma is highly collisional and stagnates on axis without significant interpenetration. More information on the dynamics can be found in a recent publication [6].

In conclusion, soft x-ray laser interferometry was used to study dense colliding aluminum plasmas formed by optical irradiation of a semi-cylindrical cavity. The measurements reveal that plasma accumulation near the axis of the cavity creates a highly collisional plasma focus with a density that exceeds $1 \times 10^{20} \text{ cm}^{-3}$. The measurements are in good agreement with hydrodynamic simulations. These results further demonstrate that soft x-ray interferometry is a powerful tool for probing dense plasmas.

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